Claims

What is claimed is:

1. A fuel injector comprising:

an injector body defining a nozzle chamber, a single nozzle outlet set and a needle control chamber, and including a needle valve seat;

a one-piece needle valve member positioned in said injector body and being movable between a closed position in contact with said needle valve seat to close said single nozzle outlet set, and an open position out of contact with said needle valve seat to open said single nozzle outlet set, and including a closing hydraulic surface exposed to fluid pressure in said needle control chamber;

said one-piece needle valve member having an effective opening hydraulic surface area in its open position that is equal to an effective area of said closing hydraulic surface;

a biasing spring positioned in said needle control chamber and being operably coupled to bias said one-piece needle valve member toward said closed position;

an electrically controlled pressure control valve attached to said injector body and having a first position and a second position;

an electronically controlled needle control valve attached to said injector body, and having a first position in which said needle control chamber is fluidly connected to a low pressure passage, and a second position in which said needle control chamber is closed to said low pressure passage; and

first and second electrical actuators attached to said injector body and being operably coupled to actuate said electronically controlled pressure control valve and said electronically controlled needle control valve, respectively.

2. The fuel injector of claim 1 wherein said electronically controlled needle control valve includes a control valve member trapped to move between a high pressure seat and a low pressure seat.

3. The fuel injector of claim 2 including a biasing spring operably coupled to bias said control valve member toward a position in contact with one of said high pressure seat and said low pressure seat.

4. The fuel injector of claim 1 wherein said nozzle chamber is fluidly connected to a spill passage when said pressure control valve is in said first position, but closed to said spill passage when in said second position.

5. The fuel injector of claim 1 wherein said electronically controlled needle control valve includes a single seat that divides said low pressure passage into an upstream segment and a downstream segment; and

said needle control chamber being fluidly connected to said fuel pressurization chamber regardless of a positioning of said electronically controlled needle control valve.

6. The fuel injector of claim 5 including a biasing spring operably positioned to bias a control valve member into contact with said single seat;

said control valve member having a net opening hydraulic surface when in contact with said single seat.

7. The fuel injector of claim 5 including a biasing spring operably positioned to bias a control valve member away from contact with said single seat.

8. The fuel injector of claim 5 including an A orifice and Z orifice disposed in said injector body;

said A orifice having a smaller flow area than said Z orifice; and

said Z orifice having a flow area smaller than a flow area across said single seat.

9. The fuel injector of claim 1 a fuel pressurizing plunger movably positioned in said injector body.

10. The fuel injector of claim 8 including a tappet operably coupled to said fuel pressurizing plunger and including a surface exposed outside said injector body.

11. A method of injecting fuel from a fuel injector, comprising the steps of:

raising fuel pressure in a nozzle chamber at least in part by energizing a first electrical actuator;

opening a single nozzle outlet set of the fuel injector at a selected timing at least in part by positioning a needle control valve at a first position that fluidly connects a needle control chamber to a low pressure passage; and

closing the single nozzle outlet set at a selected timing after the opening step using one of at least three available end modes by performing a selected one of:

de-energizing the first electrical actuator to move the pressure control valve to a first position that opens the nozzle chamber to the spill passage while maintaining the needle control valve in the first position;

equalizing opening and closing pressure forces on a needle valve member to move the needle valve member toward a closed position with a spring force by moving the needle control valve to a second position that fluidly closes the needle control chamber to the low pressure passage before de-energizing the first electrical actuator; and

equalizing opening and closing pressure forces on a needle valve member to move the needle valve member toward the closed position with the

spring force by moving the needle control valve to the second position after de-energizing the first electrical actuator.

12. The method of claim 11 wherein the opening a single nozzle outlet set step includes a step that is one of:

energizing and de-energizing the second electrical actuator to move the needle control valve from a second position to the first position.

13. The method of claim 11 wherein the needle control valve is positioned in the first position before the step of energizing the first electrical actuator.

14. The method of claim 11 wherein the opening a single nozzle outlet set step is performed at a selected valve opening pressure at least in part by one of energizing and de-energizing the second electrical actuator to move the needle control valve from a second position to the first position a predetermined timing after the step of energizing the first electrical actuator.

15. The method of claim 11 including a step of producing a split injection at least in part by moving the needle control valve from a first position to a second position and then back to the first position while the first electrical actuator remains energized.

16. The method of claim 11 wherein the step of closing the single nozzle outlet set is performed at a selected valve closing pressure at least in part by moving the needle control valve from the second position to the first position at a predetermined timing relative to de-energizing the first electrical actuator.

17. The method of claim 11 including a step of maintaining a unobstructed fluid connection between the needle control chamber and the nozzle chamber via an A orifice.

18. The method of claim 17 wherein the step of opening a single nozzle outlet set includes a step of fluidly connecting the needle control chamber to a low pressure passage via a Z orifice having a larger flow area than the A orifice.

19. The method of claim 11 wherein the raising fuel pressure step includes a step of moving a plunger into a fuel pressurization chamber within the fuel injector.

20. The method of claim 19 wherein the step of moving a plunger is accomplished at least in part by moving a tappet into the fuel injector.